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CERTIFICATION

I, Lilia Vázquez Holm, Graduate Engineer, of Onsagers AS, of Wergelandsveien 7, N-0167 OSLO, NORWAY, hereby certify that to the best of my knowledge and belief the attached document is a true translation of the originally filed US Provisional Patent Application No. 60/422,863 of 1 November 2003.

Oslo, 20 October 2003

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End piece

The present invention relates to a magnetic device for use as a part of the magnetic core in transformers and other inductive devices.

The function of the device is to constitute a flux distributor or an end piece for magnetic cores. The object of the device is to achieve greater flexibility with regard to the design of the core together with less hysteresis loss compared with the known solutions.

Magnetic core production is usually based on foil, i.e. a magnetic material which forms discrete layers, the layers being stacked on top of one another to produce flat blanks, which in turn are cut and/or rolled into the desired shape. When turning sheet metal into square cores, the raw material which is rolls of sheet metal of the desired width will be passed through a cutting machine which cuts the sheet metal into the length required. In this manner packs of sheet metal are obtained which are assembled to form the core dimension and shape estimated on the basis of the capacity required for the transformer or the inductive unit. The limitations of so-called foliated sheet metal lie more in the shape than the size. The shape of a foliated core is limited to a square or rectangular shape. One example is a magnetic core for a three-phase system consisting of three legs which are interconnected by two yokes, one at the top and one at the bottom. On the other hand, when manufacturing the ring core the raw material will be rolled up into ring cores of the desired dimension. An example of this is the ring core transformer.

There are limitations with regard to design with a magnetic core that is produced based on foil. It is restricted to cylindrical shapes such as ring cores and U-cores. In this type of core, the foils will be rolled into a cylindrical configuration. The foils may also be cut into rectangular partial shapes which are assembled to form, for example, a three-legged core for a three-phase transformer.

Another method of manufacturing magnetic cores is based on powder material, which is placed in a mould and heated under pressure (sintering). This type of core is specially adapted for converters where the AC voltage is of high frequency (10-100 kHz).

In order to achieve a low level of loss when using magnetic cores, it is important to provide a closed path for the magnetic flux generated when a winding is wound round the core and current is applied thereto.

For example, for a magnetic core comprising an inner tube part and an outer tube part which are arranged concentrically in relation to each other, where a winding is placed in the gap between the inner and the outer tube part, connectors will have to be employed at the ends of the tubes in order to provide a closed path for the flux.

For a magnetic core consisting of two tubes arranged in parallel beside each other where one or more windings are wound round the tubes, connectors may also be employed.

Where the magnetic core is made of foil material, one will be confronted with the problem of interconnecting the inner tube and the outer tube with the least possible loss. If one attempts to bend a body consisting of rolled foils, the material will be subjected to unnecessary stress and the material's magnetic properties will be reduced.

It is possible to make end pieces by means of any type of sintering, but sintered materials of iron powder and ferrites can only tolerate 20 to 30% of the flux density of cores of magnetic sheet metal. The greatest limitation therefore lies in the use as a field connector between cores that have greater flux density than the connectors made of sintered or ferrite-based materials can tolerate.

As already mentioned, the function of the end pieces is to provide a closed path for the magnetic flux. As far as the end pieces are concerned, to be capable of operating with acceptable losses, it is essential for the end pieces to establish a path which "follows" the flux lines of the magnetic flux in the core. The principle behind the known solutions is that the flux lines are forced to follow specific magnetic paths. The invention is based on the opposite principle whereby magnetic paths are placed in the natural path of the flux lines.

The object of the invention is therefore to provide end connectors, which can be adapted to different kinds of core parts, which are simple and inexpensive to produce and which result in a low level of loss.

This object is achieved by means of an end piece for magnetic coupling of core parts to a closed path for magnetic flux. The end piece according to the invention comprises at least an abutment surface for abutment against the core parts and a magnetic path part, where the path part is composed of several parallel wire-shaped bodies and the abutment surface is composed of the end surfaces of the wire-shaped bodies.

In a specially preferred embodiment of the invention the wire-shaped bodies are made of a magnetisable material, and in an even more preferred embodiment the material is iron alloyed with silicon or pure iron. Other materials that may be employed as wires are the metallic glass materials. The wire bodies are preferably electrically insulated by the application of a thin film of insulating material on the surface of the wire. The actual shape of the wire may be circular, oval, square, rectangular or it may be rolled into thin strips.

Each wire body of magnetisable material will form a path for the magnetic flux, thereby enabling the geometry of the end pieces to be easily adapted to the geometry of the core parts and the natural path of the flux.

In an embodiment of the invention the path part is hollow, i.e. the wire-shaped bodies form the surface of the end piece, and the abutment surfaces are substantially annular.

In order to better illustrate a possible embodiment of the invention, we shall use as our basis two tubular core parts, one of which is arranged inside the other. An end piece for geometry of this kind will be in the form of a half toroid which is intersected by a plane comprising the toroid's largest diameter. The end piece will thus comprise wire bodies which form arcs between an inner annular abutment surface and an outer annular abutment surface.

The toroid's largest diameter will therefore substantially correspond to the outer diameter of the outer core part and the smaller diameter will correspond to the inner diameter of the inner core part. The abutment surfaces will be an outer annular surface for abutment against the outer core part and an inner annular surface for abutment against the inner core part.

In such an embodiment of the invention the end piece is formed by winding the magnetic wire round an annular body with a round cross section ("doughnut"). Two symmetrical end pieces with a flat surface are thereby provided consisting of small areas of magnetic material arranged beside one another (the wires' cross section, whose shape depends on the shape of the wire).

An important characteristic of the end piece according to the invention is that since the abutment surfaces are composed of the end surfaces of the wire-shaped parts, the area with magnetic material in both the abutment surfaces is guaranteed to be the same. This is important since it affects the flux density in the material and the material's condition with regard to saturation. This can be easily seen in connection with a toroidal moulded body, since the toroid's inner circumference is smaller than the outer circumference, thereby giving a "thicker" layer of wire bodies on the inside of the toroid than on the outside.

A second variant of the invention is adapted for use together with core parts, which are tubular in shape, but which have to be mounted beside one another. We shall once more take a toroid as our basis, but this time the wires will be wound along the circumference of the toroid. The toroid will then be able to be divided in a plane substantially perpendicular to the circumferential direction and the resulting end piece will comprise two annular surfaces arranged beside each other, while the wire bodies form arcs round the surfaces.

It is also possible to envisage a situation where the core parts are tubular with a square cross section. In this case the basis will be a moulded body which is square in circumference with a round or square cross section.

The invention also relates to a method for producing an end piece with an abutment surface for abutment against core parts and a magnetic path part, where the method comprises the following steps:
- providing a moulded body for connection of the core parts based on the geometry of the core parts,
- winding a wire of magnetic material round the moulded body in order to create the magnetic paths,
- dividing the wire winding and the moulded body in two in order to form the abutment surfaces,
- removing the moulded body and treating the abutment surfaces in order to give them a smooth surface.

The term "wire" and "wire body" is used in the present description in order to identify a body where the length is several times greater than the width of the cross section (diameter in the case of a round cross section). Both the wire and the wire body may consist of a single wire or of a loosely wound conductor with many individual wires.

Before dividing the wire winding and the moulded body, the wire bodies are kept together by means of impregnation with a dimensionally stable material or by means of a holding mould.

A special embodiment of the method is characterised in that:
- the core parts are two concentrically arranged tubes,
- the moulded body is a toroid,
- the wire is wound round the toroid's circumferential direction,
- the moulded body and the wire winding are intersected in a plane comprising the toroid's largest diameter, with the result that the abutment surfaces form an outer ring and an inner ring for abutment against the core parts.

A second embodiment of the method is characterised in that:
- the core parts are two tubes to be placed in parallel beside each other and at a distance from each other,
- the moulded body is a toroid,
- the wire is wound round the toroid's circumferential direction,
- the moulded body and the wire winding are intersected in a plane perpendicular to the circumferential direction, with the result that the abutment surfaces form two rings for abutment against the core parts.

In a special embodiment of the latter method the moulded body is a whole toroid (doughnut) which is centred in a hollowed-out toroid with a small opening along the outer diameter whereby the wire can be inserted from the outside, the wire is wound along the toroid's circumferential direction inside the hollow toroid and will be located in the cavity between the centred and the hollow toroid, and the moulded body is provided with a gap where the wire winding can be intersected in a plane perpendicular to the circumferential direction, with the result that the abutment surfaces form two rings for abutment against the core parts.

The invention will now be explained in greater detail by means of the figures, in which:

figure 1 illustrates one of the first steps in the manufacture of a first embodiment of the invention,

figure 2 illustrates the next step in the manufacturing process,

figure 3 illustrates an end piece according to the invention,

figure 4 illustrates the areas of the abutment surfaces in the end piece in figure 3,

figure 5 illustrates the end piece in figure 3 together with core parts,

figure 6a illustrates one of the first steps in the manufacture of a second embodiment of the invention,

figure 6b illustrates a variant of the second embodiment of the invention,

figure 7 illustrates the end piece manufactured on the basis of figure 6,

figure 8 illustrates the end piece in figure 7 together with core parts,

figure 9 illustrates a moulded body for manufacture of a third embodiment of the invention,

figure 10 illustrates the wire bodies in the moulded body,

figure 11 illustrates the end piece in figure 10 with core parts.

In order to manufacture the end piece according to the invention, one will take as one's basis the geometry of the core parts and provide a moulded body adapted thereto.

If the core parts are in the form of two concentric tubes (figure 5), a moulded body 3 will be provided in the form of a toroid (figure 1a). Round this body 3 a magnetic wire will be wound in order to form wire bodies 4 (figure 1b). The wire bodies will be kept together either by means of impregnation or a special adhesive, or by means of a mould. Thereafter (figure 2) the moulded body 3 and the wire winding with the

wire bodies 4 will be intersected along a plane 5 comprising the moulded body's 3 largest diameter.

Figure 3 illustrates the end piece 6 with the end surfaces 4' of the wire bodies 4 which form the end piece's 6 abutment surface 6'.

Figure 4 illustrates that the area of the inner abutment surface 6' is the same as the area of the outer abutment surface 6'.

Figure 5 illustrates two end pieces 6 which together with the core parts 1 and 2 form a magnetic core with closed paths. If a winding 7 is provided in the gap between the core parts 1 and 2 and it is supplied with current, a magnetic field H will be created in the material. The field H is marked by arrows and it can be seen that the path for the field is closed.

If the core parts are in the form of two tubes 1 and 2 to be placed beside each other (figure 8), the moulded body 3 will still be in the form of a toroid (figure 1a), but the magnetic wire will be wound along the toroid's circumferential direction (figure 6a). This time the moulded body and the wire winding with the wire bodies 4 will be intersected in a plane 5 perpendicular to the moulded body's 3 circumferential direction, with the result that the abutment surfaces 6' form two rings for abutment against the core parts 1 and 2.

A variant of the moulded body 3 for providing an end piece for the core parts in figure 8 is illustrated in figure 6b. The moulded body in figure 6b comprises an inner toroid 3'' (doughnut) which is centred in a hollowed-out toroid 3' with a small opening 8 along the outer diameter whereby the wire 4 can be inserted from the outside, the wire 8 is wound along the toroids' circumferential direction inside the hollow toroid 3' and will be located in the cavity between the inner and the outer toroid (3'' and 3' respectively), and the moulded body is provided with a gap (not shown) where the wire winding 4 can be intersected in a plane perpendicular to the circumferential direction, with the result that the abutment surfaces 6' form two rings for abutment against the core parts 1 and 2.

Figure 8 illustrates two end pieces 6 which together with the core parts 1 and 2 form a magnetic core with closed paths. If a winding 7 is provided round one or both the core parts 1 and 2 and it is supplied with current, a magnetic field H will be created in the material. The field H is marked with arrows and it can be seen that the path for the field is closed.

If the core parts 1 and 2 are tubular in form and arranged to be placed beside each other (figure 11, core parts 1, 1', 2, 2') in a ring (the figure only shows a part of the ring), the moulded body 3 will consist of an outer toroid 3' and an inner toroid 3'', which are divided longitudinally perpendicularly to the radial direction where the

toroid has the largest diameter (figures 9 and 10). The inner toroid 3'' will then be located inside the outer 3' and the wire will be wound inside the outer toroid 3' along its circumferential direction. The moulded bodies 3' and 3'' will then be intersected in a plane perpendicular to the circumferential direction, with the result that the abutment surfaces 6' form two half rings for abutment against the core parts 1, 1'', etc.

It is of course also possible to manufacture end pieces 6 for this core by means of the moulded body, the method being described in connection with figure 6b. In this case the moulded body and the wire winding will be intersected along a plane comprising the toroid's circumference and along a plane perpendicular thereto.

The assembled core is illustrated in figure 11.

Where the core parts have a square cross section or another configuration, the moulded body will have a corresponding square or other configuration. The parameters that can be varied in order to adapt the end piece to different core parts are: a) the shape of the moulded body, b) placement of the wire bodies on the moulded body, c) the position of the plane of intersection relative to the wire bodies. With regard to c), we should mention that whilst in the described examples the plane of intersection is perpendicular to the wire body's longitudinal direction, it will be possible to intersect the wire bodies at an angle, thus obtaining a larger cross section with magnetic material for each wire body. The abutment surfaces on the core parts will then be intersected correspondingly.

The indicated manufacturing methods may also be varied, and the windings will be able to be applied by means of the different methods. The principle, however, will remain the same and such variants will fall within the scope of the invention.

PATENT CLAIMS

1. An end piece for magnetic coupling of core parts to a closed path for magnetic flux, characterised in that it comprises at least an abutment surface for abutment against the core parts and a magnetic path part, where the path part is composed of several approximately parallel, wire-shaped bodies and the abutment surface is composed of the end surfaces of the wire-shaped bodies.

2. An end piece according to claim 1, where the wire-shaped bodies are made of a magnetisable material.

3. An end piece according to claim 2, characterised in that the magnetisable material is iron.

4. An end piece according to one of the preceding claims, characterised in that the path part is hollow.

5. An end piece according to claim 4, characterised in that the wire bodies form arcs between an inner annular abutment surface and an outer annular abutment surface.

6. An end piece according to claim 4, characterised in that the wire bodies form arcs between two annular surfaces arranged beside each other.

7. An end piece according to claim 5, characterised in that the inner annular surface has the same area as the outer annular surface.

8. An end piece according to claim 6, characterised in that the annular surfaces are cylindrical with the same thickness over the whole cross-section.

9. A method for manufacturing an end piece according to one of claims 1-8, comprising the following steps:
- providing a moulded body for connecting the core parts based on the core parts' geometry,
- winding a wire of magnetic material round the moulded body in order to form the magnetic paths,
- dividing the wire winding and the mould in two in order to form the abutment surfaces,
- removing the moulded body and treating the abutment surfaces in order to give them a smooth surface.

10. A method according to claim 9,
characterised in that
- the core parts are two concentrically arranged tubes,
- the moulded body is a toroid,
- the wire is wound round the toroid's circumferential direction,
- the moulded body and the wire winding are intersected in a plane comprising the toroid's largest diameter, with the result that the abutment surfaces form an outer ring and an inner ring for abutment against the core parts.

11. A method according to claim 9,
characterised in that
- the core parts are two tubes for placing in parallel beside each other and at a distance from each other,
- the moulded body is a toroid,
- the wire is wound round the toroid's circumferential direction,
- the moulded body and the wire winding are intersected in a plane perpendicular to the circumferential direction, with the result that the abutment surfaces form two rings for abutment against the core parts.

12. A method according to claim 11,
characterised in that
- the moulded body comprises an inner toroid which is centred in an outer toroid with an opening along the outer diameter,
- the wire is inserted from the outside through the opening, and is wound along the toroid's circumferential direction within the hollow toroid,
- the moulded body is provided with a gap where the wire winding can be intersected in a plane perpendicular to the circumferential direction, with the result that the abutment surfaces form two rings for abutment against the core parts.

13. A method according to claim 9,
characterised in that
- the core parts are a number of tubes to be placed beside one another in a circle and at a distance from one another,
- the moulded body comprises an outer toroid which is divided longitudinally perpendicularly to the radial direction where the toroid has the largest diameter, and an inner toroid which is located inside the outer toroid along its circumferential direction,
- the wire is wound inside the hollow toroid along its circumferential direction,
- the moulded body and the wire winding are intersected in a plane perpendicular to the circumferential direction, with the result that the abutment surfaces form two half rings for abutment against the core parts.

ABSTRACT

The invention relates to an end piece for magnetic coupling of core parts to a closed path for magnetic flux, characterised in that it comprises at least an abutment surface for abutment against the core parts and a magnetic path part, where the path part is composed of several approximately parallel, wire-shaped bodies and the abutment surface is composed of the end surfaces of the wire-shaped bodies. The invention also relates to a method for manufacturing the end piece.

Fig. 5